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WIRELESS COMMUNICATION SYSTEMS,
INTERROGATORS AND METHODS OF
COMMUNICATING WITHIN A WIRELESS
COMMUNICATION SYSTEM

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1 WIRELESS COMMUNICATION SYSTEMS, INTERROGATORS AND
2 METHODS OF COMMUNICATING WITHIN A WIRELESS
COMMUNICATION SYSTEM

3 TECHNICAL FIELD

4 The present invention relates to wireless communication systems,
5 interrogators and methods of communicating within a wireless
6 communication system.

7
8 BACKGROUND OF THE INVENTION

9 Electronic identification systems typically comprise two devices
10 which are configured to communicate with one another. Preferred
11 configurations of the electronic identification systems are operable to
12 provide such communications via a wireless medium.

13 One such configuration is described in U.S. Patent Application
14 Serial Number 08/705,043, filed August 29, 1996, assigned to the
15 assignee of the present application, and incorporated herein by
16 reference. This application discloses the use of a radio frequency (RF)
17 communication system including communication devices. The disclosed
18 communication devices include an interrogator and a remote transponder,
19 such as a tag or card. Another example of a wireless communication
20 system including a backscatter system is described in U.S. Patent
21 No. 5,649,296 to MacLellan et al. which is also incorporated herein by
22 reference.

23 Such communication systems can be used in various applications
24 such as identification applications. The interrogator is configured to

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1 output a polling or interrogation signal which may comprise a radio
2 frequency signal including a predefined interrogation code using which
3 the interrogator may address remote transponders. The remote
4 transponders of such a communication system are operable to transmit
5 an identification signal responsive to receiving an appropriate polling or
6 interrogation signal.

7 More specifically, the appropriate transponders are configured to
8 recognize the predefined code. The transponders receiving the code can
9 subsequently output a particular identification signal which is associated
10 with the transmitting transponder. Following transmission of the polling
11 signal, the interrogator is configured to receive the identification signals
12 enabling detection of the presence of corresponding transponders.

13 Such communication systems are useable in identification
14 applications such as inventory or other object monitoring. For example,
15 a remote identification device can be attached to an object of interest.
16 Responsive to receiving the appropriate polling signal, the identification
17 device is equipped to output an identification signal. Generating the
18 identification signal identifies the presence or location of the
19 identification device and the article or object attached thereto.

20 It may be desired to communicate with remote communication
21 devices located at greater distances in particular applications. Such
22 areas may exceed the range of the communication system. Typical
23 conventional arrangements require the utilization of numerous
24 interrogators for communication with the remote communication devices

1 located in such spaced areas. Alternatively, the movement of a single
2 interrogator from one area to another is required.

3 4 SUMMARY OF THE INVENTION

5 The present invention provides wireless communication systems,
6 interrogators and methods of communicating within a wireless
7 communication system.

8 According to one aspect of the present invention, a wireless
9 communication system comprises at least one remote communication
10 device configured to communicate a return link wireless signal. The
11 return link wireless signal comprises a radio frequency signal in certain
12 aspects of the invention.

13 The wireless communication system in some embodiments includes
14 an interrogator having a communication station, communication circuitry
15 and a housing. The communication station is configured to receive the
16 return link wireless signal and to generate a return link communication
17 signal corresponding to the return link wireless signal. The
18 communication circuitry is provided to couple with the communication
19 station and to communicate the return link communication signal. The
20 housing is remotely located with respect to the communication station
21 and includes circuitry configured to receive the return link
22 communication signal from the communication circuitry and to process
23 the return link communication signal.

1 In one configuration, the housing includes automatic gain control
2 circuitry configured to adjust the power level of the return link
3 communication signals. Amplifiers can be provided within one or both
4 of the interrogator housing and the communication station to increase
5 the power level of the return link communication signals. Plural
6 communication stations and plural communication circuits are coupled
7 with a single interrogator housing in some embodiments.

8 9 BRIEF DESCRIPTION OF THE DRAWINGS

10 Preferred embodiments of the invention are described below with
11 reference to the following accompanying drawings.

12 Fig. 1 is a block diagram of an exemplary communication system
13 according to one embodiment of the present invention.

14 Fig. 2 is a front view of a wireless remote communication device
15 according to one embodiment of the invention.

16 Fig. 3 is a front view of an employee badge according to another
17 embodiment of the invention.

18 Fig. 4 is a functional block diagram of a transponder included in
19 the remote communication device of Fig. 2.

20 Fig. 5 is a functional block diagram of one embodiment of a
21 portion of an interrogator of the invention.

22 Fig. 6 is a functional block diagram of one embodiment of an RF
23 section of the interrogator of Fig. 5.

24

Fig. 7 is a functional block diagram of exemplary communication circuitry shown in Fig. 1.

Fig. 8 is a functional block diagram of exemplary transmit circuitry of a communication station shown in Fig. 1.

Fig. 9 is a functional block diagram of exemplary receive circuitry of the communication station shown in Fig. 1.

Fig. 10 is a functional block diagram of exemplary adjustment circuitry within a housing of the interrogator.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

Fig. 1 illustrates a communication system 10 embodying the invention. Communication system 10 comprises an electronic identification system in the embodiment described herein. Communication system 10 may be configured for backscatter communications as described in detail below. Other communication protocols are utilized in other embodiments.

The depicted communication system 10 includes a plurality of remote communication devices 12 and an interrogator 26. Wireless (e.g., radio frequency) communications can occur intermediate remote communication devices 12 and interrogator 26 for use in identification systems and product monitoring systems as exemplary applications.

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1 Remote communication devices 12 can include radio frequency
2 identification devices (RFID) or remote intelligent communication (RIC)
3 devices in the embodiments described herein. Exemplary remote
4 communication devices 12 are disclosed in U.S. Patent Application
5 Serial No. 08/705,043. Plural remote communication devices 12 typically
6 communicate with interrogator 26.

7 In one embodiment, remote communication devices 12 individually
8 comprise a wireless identification device such as the MicroStamp (TM)
9 integrated circuit available from Micron Communications, Inc., 3176 S.
10 Denver Way, Boise, Idaho 83705. Such a remote communication
11 device 12 can be referred to as a tag or card as illustrated and
12 described below.

13 Remote communication devices 12 are configured to interface with
14 interrogator 26 using a wireless medium in one embodiment. More
15 specifically, communications intermediate remote communication
16 devices 12 and interrogator 26 occur via an electromagnetic link, such
17 as a radio frequency link in the described embodiment. Exemplary
18 communications occur at microwave frequencies. Other configurations
19 for communication are possible.

20 As described in detail below, interrogator 26 is configured to
21 output forward link communications. Further, interrogator 26 is
22 operable to receive reply or return link communications from remote
23 communication devices 12 responsive to the outputting of forward link
24 communications. In accordance with the above, forward link

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1 communications and return link communications comprise wireless signals,
2 such as radio frequency signals, in the described embodiment. Other
3 forms of electromagnetic communication, such as infrared, acoustic, etc.,
4 are possible.

5 The depicted configuration of communication system 10 illustrates
6 interrogator 26 communicating with a plurality of remote communication
7 devices 12 located in a plurality of corresponding communication
8 ranges 15, also referred to as read zones. The depicted interrogator 26
9 includes a housing 14 coupled with a plurality of communication
10 paths 17 individually positioned and configured to communicate with
11 remote communication devices 12 located within corresponding
12 communication ranges 15. Communication paths 17 individually include
13 communication circuitry 106 and a corresponding communication
14 station 120 in the described embodiment.

15 As described in detail below, housing 14 of interrogator 26
16 includes circuitry (not shown in Fig. 1) configured to generate a
17 plurality of forward link communication signals. Such forward link
18 communication signals are communicated within communication
19 circuitry 106 of selected communication paths 17 to respective
20 communication stations 120 having antennas X1, X2 ... XN. Such
21 communication stations 120 are configured to emit forward link wireless
22 signals 27 which correspond to the forward link communication signals.
23 In addition, communication stations 120 can individually emit a
24 continuous wave signal during backscatter mode of operations of

communication system 10. Further transmit operations of interrogator 26 are described in a copending U.S. patent application filed the same day as the present application, having the title "Wireless Communication Systems, Interrogators and Methods of Communicating Within a Wireless Communication System", assigned to assignee hereof, having attorney docket number MI40-179, naming David Ovard and Roy Greeff as inventors, and incorporated herein by reference.

As illustrated, communication stations 120 are preferably configured to radiate the forward link wireless signals 27 to associated remote communication devices 12 within respective communication ranges 15. Responsive to the reception of forward link wireless signals 27, individual remote communication devices 12 are operable to reply with return link wireless signals 29.

Communication stations 120 also include plural receive antennas R1, R2 ... RN which are configured to receive return link wireless signals 29 from remote communication devices 12. Communication stations 120 of interrogator 26 preferably individually include receive circuitry configured to receive the return link wireless signals 29 and apply return link communication signals to interrogator housing 14 for processing as described in detail below. In particular, communication stations 120 generate return link communication signals corresponding to the received return link wireless signals. Communication circuits 106 communicate the return link communication signals to interrogator housing 14.

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Fig. 1 is an illustrative representation of wireless communication system 10. More specifically, communication ranges 15 may be spread out over a relatively large geographic range. The wireless communication system 10 of the present invention provides the advantages of utilizing a single interrogator housing 14 and associated communication circuitry therein to communicate with remote communication devices 12 located in plural communication ranges 15.

Further, wireless communication system 10 of the present invention permits a single interrogator housing 14 and associated circuitry to service multiple communication ranges 15 which may be located several hundred feet apart or further, or in harsh environments. For example, one interrogator housing 14 can be utilized to service read zones or communication ranges 15 within spaced warehouses. Individual communication ranges 15 may be spaced from one another at distances which exceed the communication range of the devices. Additionally, adjacent communication ranges 15 may overlap in some applications.

As previously mentioned, individual communication paths 17 include communication circuits 106 and associated communication stations 120. Communication stations 120 are preferably positioned to communicate with respective communication ranges 15. Communication circuits 106 are configured in the depicted arrangement to communicate forward link communication signals from interrogator housing 14 to corresponding communication stations 120. Communication circuits 106 are also configured to communicate return link communication signals received

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1 within corresponding communication stations 120 to interrogator
2 housing 14.

3 In the described embodiment, communication circuits 106 are
4 located outside of interrogator housing 14. In addition, communication
5 stations 120 are remotely located with respect to interrogator
6 housing 14. Communication stations 120 are individually configured to
7 receive forward link communication signals from interrogator housing 14
8 via communication circuitry 106 and radiate forward link wireless
9 signals 27 corresponding to the forward link communications signals
10 using associated antennas X1, X2 ... XN.

11 Further, communication stations 120 are individually configured to
12 receive return link wireless signals 29 from remote communication
13 devices 12 using associated antennas designated R1, R2 ... RN.
14 Communication stations 120 output return link communication signals
15 corresponding to the return link wireless signals 29 to interrogator
16 housing 14 using respective communication circuits 106.

17 Individual ones of communication stations 120 may be located at
18 varying distances from interrogator housing 14 depending upon a
19 particular application. Interrogator housing 14, communication
20 circuits 106 and communication stations 120 are configured to
21 communicate the forward link communication signals and return link
22 communication signals intermediate interrogator housing 14 and respective
23 communication stations 120 regardless of the varying distances.
24

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1 Remote communication devices 12 are individually configured for
2 wireless communications in one embodiment as described in detail below.
3 Such remote communication devices 12 receive the forward link wireless
4 signals 27 and respond with the return link wireless signals 29 which
5 are received within communication stations 120.

6 In one embodiment, return link wireless signals 29 are encoded
7 with information that uniquely identifies or labels the particular
8 device 12 that is transmitting so as to identify any object, animal or
9 person with which communication device 12 is associated. More
10 specifically, remote devices 12 are configured to output an identification
11 signal within return link wireless signals 29 responsive to receiving
12 forward link wireless signals 27. Interrogator 26 is configured to receive
13 and recognize the identification signal within the return or return link
14 communications 29. The identification signal can be utilized to identify
15 the particular transmitting remote communication device 12.

16 Referring to Fig. 2, one embodiment of a remote communication
17 device 12 is illustrated. The depicted communication device 12 includes
18 a transponder 16 having a receiver and a transmitter as described
19 below. Communication device 12 further includes a power source 18
20 connected to transponder 16 to supply operational power to
21 transponder 16. In the illustrated embodiment, transponder 16 is in the
22 form of an integrated circuit 19. However, in alternative embodiments,
23 all of the circuitry of transponder 16 is not necessarily included in
24 integrated circuit 19.

Power source 18 is a thin film battery in the illustrated embodiment, however, in alternative embodiments, other forms of power sources can be employed. If the power source 18 is a battery, the battery can take any suitable form. Preferably, the battery type will be selected depending on weight, size and life requirements for a particular application. In one embodiment, battery 18 is a thin profile button-type cell forming a small, thin energy cell more commonly utilized in watches and small electronic devices requiring a thin profile. A conventional button-type cell has a pair of electrodes, an anode formed by one face and a cathode formed by an opposite face. In an alternative embodiment, the battery comprises a series connected pair of button type cells.

Communication device 12 further includes at least one antenna connected to transponder 16 for wireless transmission and reception. In the illustrated embodiment, communication device 12 includes at least one receive antenna 44 connected to transponder 16 for radio frequency reception by transponder 16, and at least one transmit antenna 46 connected to transponder 16 for radio frequency transmission by transponder 16. The described receive antenna 44 comprises a loop antenna and the transmit antenna 46 comprises a dipole antenna.

Remote communication device 12 can be included in any appropriate housing or packaging. Fig. 2 shows but one example of a housing in the form of a miniature housing 11 encasing device 12 to

define a tag which can be supported by an object (e.g., hung from an object, affixed to an object, etc.).

Referring to Fig. 3, an alternative housing is illustrated. Fig. 3 shows a housing in the form of a card 13. Card 13 preferably comprises plastic or other suitable material. Plastic card 13 houses communication device 12 to define an employee identification badge including the communication device 12. In one embodiment, the front face of card 13 has visual identification features such as an employee photograph or a fingerprint in addition to identifying text.

Although two particular types of housings have been disclosed, the communication device 12 can be included in any appropriate housing. Communication device 12 is preferably of a small size that lends itself to applications employing small housings, such as cards, miniature tags, etc. Larger housings can also be employed. The communication device 12, provided in any appropriate housing, can be supported from or attached to an object in any desired manner.

Fig. 4 is a high level circuit schematic of an embodiment of transponder 16 utilized in remote communication devices 12. In the embodiment shown in Fig. 4, transponder 16 is implemented within a monolithic integrated circuit 19. In the illustrated embodiment, integrated circuit 19 comprises a single die, having a size of 209 x 116 mils², including a receiver 30, a transmitter 32, a microcontroller or microprocessor 34, a wake up timer and logic circuit 36, a clock recovery and data recovery circuit 38, and a bias voltage and current

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1 generator 42. Integrated circuit 19 preferably comprises a small outline
2 integrated circuit (SOIC) package. Receiver 30 and transmitter 32
3 comprise wireless communication circuitry configured to communicate
4 wireless signals.

5 In one embodiment, communication devices 12 switch between a
6 "sleep" mode of operation, and higher power modes to conserve energy
7 and extend battery life during periods of time where no interrogation
8 signal 27 is received by devices 12, using the wake up timer and logic
9 circuitry 36.

10 In one embodiment, a spread spectrum processing circuit 40 is
11 included in transponder 16. In this embodiment, signals transmitted and
12 received by interrogator 26 and signals transmitted and received by
13 communication device 12 are modulated spread spectrum signals. Many
14 modulation techniques minimize required transmission bandwidth.
15 However, the spread spectrum modulation techniques employed in the
16 illustrated embodiment require a transmission bandwidth that is up to
17 several orders of magnitude greater than the minimum required signal
18 bandwidth. Although spread spectrum modulation techniques are
19 bandwidth inefficient in single user applications, they are advantageous
20 where there are multiple users, as is the case with the preferred radio
21 frequency identification communication system 10 of the present
22 invention.

23 The spread spectrum modulation technique of the illustrated
24 embodiment is advantageous because the interrogator signal can be

1 distinguished from other signals (e.g., radar, microwave ovens, etc.)
2 operating at the same frequency. The spread spectrum signals
3 transmitted by communication device 12 and interrogator 26 are pseudo
4 random and have noise-like properties when compared with the digital
5 command or reply. The illustrated embodiment employs direct sequence
6 spread spectrum (DSSS) modulation.

7 In operation, interrogator 26 sends out a command that is spread
8 around a certain center frequency (e.g., 2.44 GHz). After the
9 interrogator transmits the command, and is expecting a response, the
10 interrogator switches to a continuous wave (CW) mode for backscatter
11 communications. In the continuous wave mode, interrogator 26 does not
12 transmit any information. Instead, the interrogator just transmits a
13 radio frequency continuous wave signal. In the described embodiment,
14 the continuous wave signal comprises a radio frequency 2.44 GHz carrier
15 signal. In other words, the continuous wave signal transmitted by
16 interrogator 26 is not modulated. After communication device 12
17 receives the forward link communication from interrogator 26,
18 communication device 12 processes the command.

19 If communication device 12 is operating in a backscatter mode,
20 device 12 modulates the continuous wave signal providing a modulated
21 continuous wave signal to communicate return link communication 29
22 responsive to reception of forward communication signal 27.
23 Communication device 12 may modulate the continuous wave signal
24 according to a subcarrier or modulation signal. Modulation by

1 device 12 comprises selective reflection of the continuous wave signal.
 2 In particular, device 12 alternately reflects or does not reflect the
 3 continuous wave signal from the interrogator to send its reply. For
 4 example, in the illustrated embodiment, two halves of a dipole antenna
 5 are either shorted together or isolated from each other to send a reply.
 6 Alternatively, communication device 12 can communicate in an active
 7 mode.

8 The modulated continuous wave signal communicated from
 9 device 12 comprises a carrier component and plural side band
 10 components about the carrier component resulting from the modulation.
 11 More specifically, the modulated continuous wave signal output from
 12 device 12 includes a radio frequency continuous wave signal having a
 13 first frequency (2.44 GHz), also referred to as a carrier component, and
 14 a subcarrier modulation signal having a different frequency (e.g., 600
 15 kHz) which provides the side band components. In particular, the side
 16 band components are at +/- 600 kHz of the carrier component.

17 In one embodiment, the clock for transponder 16 is extracted
 18 from the incoming message itself by clock recovery and data recovery
 19 circuitry 38. This clock is recovered from the incoming message and
 20 used for timing for microcontroller 34 and all the other clock circuitry
 21 on the chip and also for deriving the transmitter carrier or the
 22 subcarrier, depending on whether the transmitter is operating in active
 23 mode or backscatter mode.
 24

In addition to recovering a clock, the clock recovery and data recovery circuit 38 also performs data recovery on valid incoming signals. The valid spread spectrum incoming signal is passed through the spread spectrum processing circuit 40 which extracts the actual ones and zeros of data from the incoming signal. More particularly, the spread spectrum processing circuit 40 takes chips from the spread spectrum signal and reduces individual thirty-one chip sections down to a bit of one or zero, which is passed to microcontroller 34.

Microcontroller 34 includes a serial processor, or I/O, facility that receives the bits from spread spectrum processing circuit 40. The microcontroller 34 performs further error correction. More particularly, a modified hamming code is employed, wherein each eight bits of data is accompanied by five check bits used by the microcontroller 34 for error correction. Microcontroller 34 further includes a memory, and after performing the data correction, microcontroller 34 stores bytes of the data bits in memory. These bytes contain a command sent by the interrogator 26. Microcontroller 34 is configured to respond to the command.

For example, interrogator 26 may send a command requesting that any communication device 12 in the field respond with the device's identification number. Status information can also be returned to interrogator 26 from remote communication devices 12. Additionally, remote communication devices 12 may be individually coupled with a

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1 peripheral device and information regarding the peripheral device may
2 also be communicated.

3 Communications from interrogator 26 (i.e., forward link
4 communications) and devices 12 (i.e., return link communications) have
5 a similar format. More particularly, the forward and return
6 communications individually include a calibration period, preamble and
7 Barker or start code which are followed by actual data in the described
8 embodiment. The incoming forward link message and outgoing return
9 preferably also include a check sum or redundancy code so that
10 transponder 16 or interrogator 26 can confirm receipt of the entire
11 forward message or return message.

12 Communication devices 12 typically include an identification
13 sequence identifying the particular tag or device 12 sending the return
14 link signal. Such implements the identification operations of
15 communication system 10.

16 After sending a command, interrogator 26 sends the unmodulated
17 continuous wave signal. Return link data can be Differential Phase
18 Shift Key (DPSK) modulated onto the continuous wave signal using a
19 square wave subcarrier with a frequency of approximately 600 kHz
20 (e.g., 596.1 kHz in one embodiment). A data 0 corresponds to one
21 phase and data 1 corresponds to another, shifted 180 degrees from the
22 first phase.

23 The subcarrier or modulation signal is used to modulate antenna
24 impedance of transponder 16 and generate the modulated continuous

1 wave signal. For a simple dipole, a switch between the two halves of
2 the dipole antenna is opened and closed. When the switch is closed,
3 the antenna becomes the electrical equivalent of a single half-wavelength
4 antenna that reflects a portion of the power being transmitted by the
5 interrogator. When the switch is open, the antenna becomes the
6 electrical equivalent of two quarter-wavelength antennas that reflect very
7 little of the power transmitted by the interrogator. In one embodiment,
8 the dipole antenna is a printed microstrip half-wavelength dipole
9 antenna.

10 Referring to Fig. 5, one embodiment of interrogator housing 14
11 and the internal circuitry therein is illustrated. The depicted
12 interrogator housing 14 generally includes a microcontroller 70, a field
13 programmable gate array (FPGA) 72 and RF section 74. In the
14 depicted embodiment, microcontroller 70 comprises a MC68340
15 microcontroller available from Motorola, Inc. FPGA 72 comprises
16 an XC4028 device available from Xilinx, Inc. Further details of
17 components 70, 72 and 74 are described below.

18 Interrogator housing 14 also includes RAM 76, EPROM 78 and
19 flash memory 80 coupled with microcontroller 70 in the depicted
20 embodiment. Microcontroller 70 is configured to access an applications
21 program from EPROM 78 for controlling the interrogator 26 and
22 interpreting responses from remote communication devices 12.

23 The processor of microcontroller 70 is configured to control
24 communication operations with remote communication devices 12 during

1 normal modes of operation. The applications program can also include
2 a library of radio frequency identification device applications or
3 functions. These functions effect radio frequency communications
4 between interrogator 26 and associated remote communication devices 12.

5 Microcontroller 70 includes circuitry configured to generate forward
6 link communication signals to be communicated to remote communication
7 devices 12. Further, microcontroller 70 is also configured to process
8 return link communication signals received from remote communication
9 devices 12. Alternatively, an external processor or computer (not
10 shown) can be coupled with interrogator 26 to process the return link
11 communication signals.

12 RF section 74 is configured to implement wireless (e.g., radio
13 frequency) communications with remote communication devices 12.
14 DPSK modulation techniques can be utilized for communications
15 intermediate devices 12 and interrogator 26. RF section 74 can include
16 downconversion circuitry for generating in-phase (I) and quadrature (Q)
17 signals which contain the DPSK modulated subcarrier for application
18 to FPGA 72 during return link communications.

19 Analog to digital (A/D) converters 82, 84 provide received
20 analog RF signals into a digital format for application to FPGA 72.
21 In particular, analog to digital converters 82, 84 are implemented
22 intermediate FPGA 72 and RF section 74 for both in-phase (I) and
23 quadrature (Q) communication lines.

24

1 An additional connection 85 is provided intermediate FPGA 72
2 and RF section 74 for forward link communication signals. Digital
3 signals to be communicated from interrogator 26 are outputted
4 from FPGA 72 via connection 85 and converted to RF forward link
5 communication signals by RF section 74. Connection 85 can additionally
6 be utilized to transmit phase lock loop (PLL) information and other
7 necessary communication information. During forward link
8 communications, FPGA 72 is configured to provide communication
9 packets received from microcontroller 70 into a proper format for
10 application to RF section 74 for communication.

11 FPGA 72 is configured to demodulate return link communications
12 received from remote communication devices 12 via RF section 74.
13 FPGA 72 is configured in the described embodiment to perform I
14 and Q combination operations during receive operations. The described
15 FPGA 74 further includes delay and multiplication circuitry to remove
16 the subcarrier. FPGA 74 can also include bit synchronization circuitry
17 and lock detection circuitry. Data, clock and lock detection signals
18 generated within FPGA 74 are applied to microcontroller 70 for
19 processing in the described embodiment.

20 Microcontroller 70 is configured to control operations of
21 interrogator 26 including outputting of forward link communications and
22 receiving return link communications. EPROM 78 is configured to store
23 original applications program codes and settings selected for the
24 particular application of communication system 10. Flash memory 80

1 is configured to receive software code updates which may be forwarded
2 to interrogator 26.

3 RAM device 76 is configured to store data during operations of
4 communication system 10. Such data can include information regarding
5 communications with associated remote communication devices 12 and
6 status information of interrogator 26 during normal modes of operation.

7 In accordance with the described embodiment, RF section 74 of
8 interrogator housing 14 is coupled with plural communication circuits 106
9 as shown in Fig. 1. Microcontroller 70 is configured to select an
10 appropriate communication circuit 106 to implement forward link and
11 return link communications with desired remote communication
12 devices 12 within respective communication ranges 15. RF section 74
13 includes switching circuitry configured to selectively couple one of
14 communication circuits 106 with RF circuitry within RF section 74 as
15 well as connection 85 and analog to digital converters 82, 84. Such
16 switching is controlled by microcontroller 70 depending upon the
17 individual communication range 15 presently communicating with
18 interrogator 26.

19 For example, microcontroller 70 can initially select one of
20 communication paths 17 to provide communications of interrogator 26
21 with remote communication devices 12 within the communication
22 range 15 which corresponds to the originally selected path 17.
23 Thereafter, microcontroller 70 can select another one of communication
24 paths 17 using switching circuitry of RF section 74 to provide

1 communications of interrogator 26 with remote communication devices 12
2 within the communication range 15 which corresponds to the newly
3 selected path 17.

4 Exemplary switching operations of the communication paths 17 can
5 be performed under control of microcontroller 70 after individual
6 forward link communications to respective communication paths 17 and
7 corresponding communication ranges 15 occur in one operational mode.
8 Alternatively, microcontroller 70 can switch communication paths 17 after
9 forward link communications and return link communications occur with
10 a desired communication range 15. Other communication switching
11 protocols can be utilized in other configurations.

12 Referring to Fig. 6, an exemplary configuration of RF circuitry 74
13 is illustrated. The depicted RF circuitry 74 includes a transmit path 86
14 and a receive path 87. Communication paths 86, 87 are coupled
15 with RF control circuitry 97. Transmit path 86 is additionally coupled
16 with FPGA 72 shown in Fig. 5 via connection 85. Receive path 87 is
17 coupled with analog to digital converters 82, 84 shown in Fig. 5 via
18 the I and Q connection lines.

19 Forward link communication signals are communicated via path 86
20 while return link communication signals are communicated via path 87.
21 In the depicted embodiment, RF section 74 additionally includes a
22 transmitter 90 and driver amplifier 92 within transmit data path 86.
23 Receive path 87 includes a receiver 95 and adjustment circuitry 96 in
24 the described embodiment.

Transmitter 90 is configured to implement radio frequency modulation operations in the described embodiment using the forward link communication signal previously generated. The modulated forward link communication signal outputted from transmitter 90 is applied to driver amplifier 92. Driver amplifier 92 is configured to increase the power level of the forward link communication signal. In typical implementations, driver amplifier 92 is configured to provide a gain of approximately 10-15 dB. Amplifiers providing more or less gain may be utilized depending upon the specific application and expected loss within communication circuitry 106.

Thereafter, driver amplifier 92 applies the amplified forward link communication signal to an input of a selected communication circuit 106 responsive to control from microcontroller 70 and using RF control 97. In the described configuration, RF control 97 comprises switching circuitry configured to selectively couple transmit path 86 and receive path 87 with a selected one (or ones) of communication circuitry 106. RF control 97 implements the switching operations to selectively couple communication circuits 106 with transmit path 86 and receive path 87 responsive to control from microcontroller 70.

Depending upon the particular application for use of communication system 10 or location of associated communication stations 120, communication circuits 106 can be individually implemented in one of a variety of configurations. Communication circuits 106 are located outside of interrogator housing 14 and are coupled with driver

1 amplifier 92 and adjustment circuitry 96 via RF control 97.
2 Communication circuits 106 are individually configured to communicate
3 the forward link communication signals and return link communication
4 signals within the corresponding communication path 17 intermediate
5 housing 14 and the corresponding communication station 120.

6 In some embodiments, communication circuits 106 individually
7 comprise coaxial RF cable. Depending upon the distance intermediate
8 housing 14 and the corresponding communication station 120, low-loss
9 coaxial RF cable may be utilized. Further, amplifiers having increased
10 gain may be utilized in addition to the described amplifiers to increase
11 the power level of the forward link communication signals and return
12 link communication signals being communicated within communication
13 circuitry 106. Various combinations of components can be utilized
14 depending upon the particular application and associated loss to ensure
15 that the forward link communication signals and return link
16 communication signals outputted from communication circuitry 106 are
17 at a power level sufficiently above the thermal noise.

18 Referring to Fig. 7, an alternative configuration of communication
19 circuitry 106 which may be utilized within individual communication
20 paths 17 is illustrated. The depicted communication circuitry 106
21 includes a plurality of transceivers 108, 109 individually coupled with one
22 of interrogator housing 14 and one of communication stations 120.
23 Transceivers 108, 109 operate to communicate forward link
24 communication signals and return link communication signals intermediate

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interrogator housing 14 and the corresponding communication station 120. In an exemplary configuration, transceivers 108, 109 are configured to communicate utilizing electromagnetic signals, such as radio frequency signals. Such signals are preferably communicated outside of the frequency band of forward link wireless signals 27 and return link wireless signals 29.

Referring to Fig. 8, an exemplary embodiment of one of communication stations 120 is illustrated. The depicted communication station 120 is coupled with communication circuitry 106. The depicted communication station 120 includes transmit circuitry 121 and receive circuitry 123. Transmit circuitry 121 is coupled with the X1 antenna 126 and receive circuitry 123 is coupled with the R1 antenna 128. One configuration of transmit circuitry 121 is described with reference to Fig. 8, and one configuration of receive circuitry 123 is described with reference to Fig. 9.

The depicted transmit circuitry 121 shown in Fig. 8 includes adjustment circuitry 122, a power amplifier 124 and a potentiometer 137. Forward link communication signals received from communication circuitry 106 are applied to transmit circuitry 121. Forward link wireless signals 27 corresponding to the forward link communication signals are radiated using antenna 126. Return link wireless signals 29 are received by R1 antenna 128 and applied to receive circuitry 123. Receive circuitry 123 outputs return link communication signals

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1 corresponding to the return link wireless signals to communication
2 circuitry 106.

3 Referring to transmit operations, forward link communication
4 signals from communication circuitry 106 are initially applied to
5 adjustment circuitry 122 within transmit circuitry 121. Adjustment
6 circuitry 122 is configured to receive the forward link communication
7 signals from communication circuitry 106 and to adjust at least one
8 electrical characteristic of the forward link communication signals. In
9 an exemplary configuration, adjustment circuitry 120 is configured to
10 adjust the power level of the forward link communication signal.

11 More specifically, the depicted adjustment circuitry 122 comprises
12 automatic gain control (AGC) circuitry. In particular, the automatic
13 gain control circuitry is configured to monitor the power of the forward
14 link communication signals, compare the power with a predetermined
15 threshold value and adjust the power of the forward link communication
16 signals responsive to the comparison.

17 Adjustment circuitry 122 comprising automatic gain control circuitry
18 includes a variable gain amplifier 130, a coupler 132, a detector 134
19 and a loop filter 136 in an exemplary configuration. Forward link
20 communication signals received from communication circuitry 106 are
21 applied to coupler 132. Coupler 132 directs a portion of the power
22 of the forward link communication signals to detector 134 which
23 converts the received power into a voltage.
24

1 The converted voltage is directed to loop filter 136. Loop
2 filter 136 is additionally coupled with a potentiometer 137 in the
3 described configuration. Potentiometer 137 can be utilized to provide
4 an adjustable threshold reference voltage. Potentiometer 137 may be
5 varied to fine tune individual communication stations 120 depending
6 upon the distance intermediate the communication station 120 and
7 interrogator housing 14 (e.g., the threshold reference voltage can be
8 varied to accommodate varying amounts of loss intermediate individual
9 communication stations 120 and the corresponding interrogator
10 housing 14).

11 Loop filter 136 compares the received voltage from detector 134
12 representing the power level of the received forward link communication
13 signals with the adjustable reference voltage determined by
14 potentiometer 137. Thereafter, loop filter 136 outputs a control signal
15 to variable gain amplifier 130 to adjust the power of the forward link
16 communication signals applied to power amplifier 124 responsive to the
17 comparison.

18 Preferably, variable gain amplifier 130 provides forward link
19 communication signals to power amplifier 124 which have a substantially
20 constant input power level as determined by potentiometer 137. Such
21 is preferred to provide linear operation of power amplifier 124. Power
22 amplifier 124 amplifies the forward link communication signals. It is
23 preferred to provide forward link communication signals of
24 approximately 1 mW to power amplifier 124 which comprises a 1 watt

1 amplifier in one embodiment operable to provide approximately 30 dB
2 of gain.

3 The output of power amplifier 124 is applied to the X1
4 antenna 126. Preferably, the distance intermediate power amplifier 124
5 and the X1 antenna 126 is minimized. X1 antenna 126 is operable to
6 receive the amplified forward link communication signals 27 from power
7 amplifier 124 and to radiate forward link wireless signals 27
8 corresponding to the forward link communication signals. X1
9 antenna 126 of the corresponding communication station 120 is
10 preferably positioned to radiate the forward link wireless signals 27
11 within at least one of the plurality of communication ranges 15.

12 Referring to Fig. 9, details of receive circuitry 123 are illustrated.
13 Receive circuitry 123 is coupled with communication circuitry 106
14 and R1 antenna 128. The illustrated receive circuitry 123 includes a
15 low noise amplifier (LNA) 140 coupled with an amplifier 142. The R1
16 antenna 128 is coupled with low noise amplifier 140. R1 antenna 128
17 receives return link wireless signals 29 from remote communication
18 devices 12 located within one or more of communication ranges 15.
19 Antenna 128 outputs return link communication signals corresponding to
20 the return link wireless signals 29 to low noise amplifier 140.

21 Preferably, the distance intermediate the R1 antenna 128 and the
22 low noise amplifier 140 is minimized. The low noise amplifier 140 is
23 configured to receive the return link communication signals and increase
24 the power of the return link communication signals. Such amplification

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1 preferably increases the level of the return link communication signals
2 to a sufficient degree above the thermal noise.

3 The return link communication signals are thereafter applied to
4 amplifier 142 which has a gain to further increase the power level of
5 the return link communication signals. In an exemplary configuration,
6 amplifiers 140, 142 individually have a gain of approximately 15 dB.
7 Receive circuitry 123 is merely exemplary and can be configured to
8 provide more or less gain depending upon the expected loss within
9 communication circuitry 106. In one configuration, amplifier 142 also
10 comprises a low noise amplifier.

11 Preferably, receive circuitry 123 and communication circuitry 106
12 are configured to provide return link communication signals to the
13 interrogator housing 14 having a sufficient signal-to-noise ratio. As
14 previously described, communication circuitry 106 comprising coaxial RF
15 cable, transceivers or other configurations communicates the return link
16 communication signals to interrogator housing 14.

17 Referring to Fig. 10, return link communication signals received
18 within communication station 120 and communicated using communication
19 circuitry 106 are applied to RF control 97 within interrogator
20 housing 14. RF control 97 operates to selectively couple one of
21 communication circuits 106 with receive path 87 responsive to control
22 from microcontroller 70 as described above.

23 Return link communication signals from RF control 97 are applied
24 to adjustment circuitry 96 within housing 14. Adjustment circuitry 96

1 is configured to receive the return link communication signals from RF
2 control 97 and to adjust at least one electrical characteristic of the
3 return link communication signals. In an exemplary configuration,
4 adjustment circuitry 96 is configured to adjust the power level of the
5 return link communication signals.

6 More specifically, the depicted adjustment circuitry 96 comprises
7 automatic gain control (AGC) circuitry. The automatic gain control
8 circuitry is configured to monitor the power of the return link
9 communication signals, compare the power with a threshold value and
10 adjust the power of the return link communication signals responsive to
11 the comparison.

12 Adjustment circuitry 96 comprising automatic gain control circuitry
13 includes a variable gain amplifier 150, a coupler 152, a detector 154
14 and a loop filter 156. Return link communication signals received
15 from RF control 97 are applied to variable gain amplifier 150 which
16 adjusts the power level of the return link communication signals
17 responsive to control from loop filter 156. Coupler 152 directs a
18 portion of the power of the return link communication signals to
19 detector 154 which converts the received power into a voltage. The
20 converted voltage is directed to loop filter 156.

21 Loop filter 156 compares the received voltage from detector 154
22 representing the power level of the return link communication signals
23 with a reference voltage. Thereafter, loop filter 156 outputs a control
24 signal to variable gain amplifier 150 which adjusts the power of the

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1 return link communication signals applied to receiver 95 responsive to
2 the comparison. Although not shown, circuitry may be provided to
3 permit adjustment of the reference voltage of loop filter 156 similar to
4 that of potentiometer 137 of communication station 120.

5 Preferably, variable gain amplifier 150 provides return link
6 communication signals to receiver 95 which have a substantially constant
7 or fixed input level. In one embodiment, adjustment circuitry 96 is
8 configured to output rerun link communication signals having a power
9 level of approximately 3 dBm. Such is preferred to avoid saturation
10 of components (e.g., downconversion circuitry) within receiver 95. The
11 return link communication signals may be processed by
12 microcontroller 70 or other circuitry following demodulation of the
13 return link communication signals.

14 In compliance with the statute, the invention has been described
15 in language more or less specific as to structural and methodical
16 features. It is to be understood, however, that the invention is not
17 limited to the specific features shown and described, since the means
18 herein disclosed comprise preferred forms of putting the invention into
19 effect. The invention is, therefore, claimed in any of its forms or
20 modifications within the proper scope of the appended claims
21 appropriately interpreted in accordance with the doctrine of equivalents.
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